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BALL MOUNTING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a ball mounting apparatus and ball mounting method for sucking up balls, which are used when an integrated circuit is mounted on a substrate or a substrate-mounted integrated circuits is mounted on other large substrate, to a ball transfer member which is called a head, and mounting the balls on a workpiece.

Description of the Related Art

In conventional ball mounting apparatus and methods, various counterbalance mechanisms for heads have been devised heretofore to avoid overload applied to balls by a head when the head mounts the balls onto a workpiece such as semiconductor integrated circuits, circuit boards and so on. Such apparatus and methods are described in U.S. Pat. No. 5,768,775 and Japanese Patent Application Laid-Open Hei 9-18129. The apparatus described in U.S. Pat. No. 5,768,775 has a spring force that cancels a self-weight of the head, but the device has the disadvantage that vibration occurs when the head moves at middle or high speed because the head is not clamped.

According to an apparatus and method described in Hei 9-18129, a head weight is not counterbalanced by a spring tension force, but a lifting force of a cylinder. In the case of counterbalancing the head weight, there are hence two disadvantages about the apparatus and method described above. First, it is difficult to position the head at a predetermined position in a counterbalanced condition. Second, upon moving, a clamping force of the head is weak since the head is fixed only by the self-weight of the head. The first disadvantage of the techniques described in Hei 9-18129 is as follows. If the lifting force of the cylinder is even slightly strong than a total weight of the head and elements moving with the head (hereafter "head weight"), the head raises and stops at an upper moving limit of the cylinder. On the contrary, if the lifting force of the cylinder is weaker than the head weight, the head lowers and stops at a lower moving limit of the cylinder. Only in the case where the lifting force of the cylinder is equal to the head weight, the head stops in a counterbalanced condition. But, even in the counterbalanced condition, the head moves some distance until a velocity of the head damps due to friction of the cylinder. That is to say, a stop position of the head is not definite. In this manner, the apparatus which uses a cylinder for a balancer has a serious disadvantage. The second disadvantage is as

follows. In the case where the head quickly stops when raising or lowering, the head vibrates up and down whether the head weight is heavy or light, because the head is fixed only by the self-weight of the head. The vibration does not cease until the vibration is damped by friction of the cylinder. Only one condition moving the head in a quasi-static state can avoid the vibration, so it is not practical. As mentioned above, a serious disadvantage, in practical use, belongs to an apparatus of which the head is clamped only by the self-weight of the head.

SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a counterbalance type ball mounting apparatus and method in which the head weight is counterbalanced that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

An object of the present invention is to provide an apparatus and method which prevent vibration from occurring when the head moves and besides easily perform a high degree of positioning accuracy.

To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, the present invention provides an apparatus comprising a positioning mechanism for positioning the workpiece, a ball supply device for supplying the balls, a head for sucking up the balls, an energized force generating device for energizing the head in an upward direction, a clamping device for clamping the head, and a moving mechanism for moving the head.

A spring member for the energized force generating device may be designed to provide with an energized force which is able to lift the head above the lower positioning. The clamping device also may be designed to comprise a cylinder and a lower positioning. Moreover, suction pads which fix the workpiece to a holding table may be designed to be bellows-shaped pads.

In another aspect, the present invention provides a ball mounting method characterized by counterbalancing with the head weight and the energized force of the energized force generating device to be substantially zero through releasing a pressure of the cylinder in accordance with necessity. More specifically, the ball mounting method of the present invention includes the sequential steps of lowering a clamped head toward a ball supply section, sucking up the balls to the head from the ball supply section, moving the head to above the workpiece, releasing a clamping force clamping the head to the lower positioning, mounting the balls sucked

up to the head on the workpiece, clamping the head, and moving the head above the ball supply section.

In the step of clamping the head to the lower positioning, the clamping force may be in the range of 2 to 30Kgf. In the step of sucking up the balls to the head, an area where the balls occupy may be 5% to 80% by area for a bottom area of the container. In the step of sucking up the balls to the head, the head may suck up the balls again after temporarily stopping sucking up the balls to disperse aggregated balls. Further, the ball mounting method of the present invention may include the steps of counterbalancing the head weight substantially to zero, lowering each tip of the balls to a bottom of a flux layer, and applying the flux to the balls. Furthermore, the mounting method of the present invention may include a step of applying a conductive adhesive to the balls after sucking up conductive balls to the head. In the step of mounting the balls sucked up to the head on the workpiece, a force for clamping the head to the lower positioning with a pressure of the cylinder may be less than or equal to 1Kgf. The ball mounting method of the present invention may include a step of knocking the head with a hammer such that extra balls remained on the head are dropped, after the step of mounting the balls on the workpiece.

Additional features and advantages of the invention will be set forth in the descriptions that follow and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the present invention will be explained with reference to the accompanying drawings, in which:

Figure 1 is a front view showing a ball mounting apparatus according to an embodiment of the present invention.

Figs. 2(A) and 2(B) show a typical packing state of the balls packed in a ball supply section of the ball mounting apparatus shown in Fig.1. Fig. 2(A) shows a state of the balls which are piled in several layers, and Fig. 2(B) shows a state of the balls which lie scattered sparsely.

Figs. 3(A) and 3(B) show a holding table of the ball mounting apparatus shown in Fig.1. Fig. 3(A) is a plan view of the holding table with bellows-shaped suction pads, and Fig. 3(B) is a cross-sectional view thereof.

Fig.4 shows a second embodiment related to structures of the head and peripheral devices which are used on the ball mounting apparatus shown in Fig.1, in a cross-sectional view showing a counterbalance mechanism and a clamping device for the head.

Fig.5 shows a third embodiment according to structures of the head and peripheral devices which are used on the ball mounting apparatus shown in Fig.1, in a side elevation showing a mechanism portion including a counterbalancing mechanism, a clamping device and a moving mechanism for the head.

Fig. 6 is a cross-sectional view showing a flux supply mechanism for the ball mounting apparatus shown in Fig. 1.

Fig.7 is a flowchart showing a ball mounting method according to an embodiment of the present invention, performed by using the ball mounting apparatus shown in Figs.1 to 6.

Figs. 8(A)-8(F) schematically show the steps of applying the flux to the balls and mounting the balls to which this flux is applied onto the workpiece.

Fig.9 is a flowchart showing a ball mounting method according to another embodiment of the present invention, is carried out using the ball mounting apparatus shown in Figs.1 to 6.

Figs. 10(A) and 10(B) show a head portion in which the single-acting cylinder is attached to the head of the ball mounting apparatus shown in embodiments of the present invention. Fig. 10(A) is a front view, and Fig. 10(B) is a plan view showing the head describing positions where the single-acting cylinder for imparting vibrations knocks the head.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG.1 is a plan view showing an overall structure of a ball mounting apparatus according to an embodiment of the present invention. Numeral 1 denotes a ball supply section. Numeral 2 denotes a ball. Numeral 3 denotes a vibrator that imparts vibration to the balls. Numeral 4 denotes a head. Numeral 5 denotes a head bottom wherein a plurality of suction holes 25 for vacuum-absorbing the balls 2 (see fig.4) are machined. Numeral 6 denotes a cavity of the head 4. Numeral 7 denotes a XYZθ table 7 for the head which positions the head 4. Numeral 8 denotes a base on which the XYZθ table for the head moves. Numeral 9 denotes a Z-direction drive unit that moves the base 8 at a distance in the Z-direction. Numeral 10 denotes a vacuum pump that reduces suction pressure of the cavity 6 of the head 4 and a holding table 23 for the workpiece 12 (see Fig.3). Numeral 11 denotes a line light source for inspecting suction errors. Numeral 12 denotes a workpiece on which the balls 2 are mounted. Numeral 13 denotes a XYZθ table for the workpiece. Numeral 14 denotes a case. Numeral 22 denotes an X-direction drive unit which moves the XYZθ table 7 for the head in the X-direction.

In the cavity 6 is disposed either one or the plural of light detecting sensors, a sound detecting sensor, a pressure gage sensor or an air flowing rate sensor to inspect ball pickup errors. When the head 4 passes above the line light source, the light detecting sensors detect leakage light through the suction holes 25 which do not suck up the balls to determine the presence of suction errors. In this embodiment, the light detecting sensor has been selected. The sound detecting sensor detects sound generated when air is sucked through the suction hole 25, and determines that the balls 2 are sucked to all the suction holes 25 when the sound are not uttered. Since a pressure in the cavity 6 is rapidly reduced in the condition that all the suction holes 25 sucks up the balls 2, the pressure gage sensor judges an absorption sate of the balls 2 through a degree of vacuum or a differential coefficient of the degree of vacuum. The air flowing sensor is arranged near the cavity 6 connected with the vacuum pump 10 and measures a gas flow rate sucked by the vacuum pump 10 to determine a suction state of the balls 2.

The ball supply section 1 is also a container for receiving the balls 2 from a ball feed device (not shown). The ball feed device is such as a parts feeding machine provided a mechanism which automatically supply a predetermined amount of the balls 2 to the container whenever an amount of the balls 2 decreases. The ball supply device of the present invention is composed of the ball supply section 1, the vibrator 3 and the ball feed device.

Fig.2 shows a typical example of a packing state of the balls 2. In the case of Fig. 2(A) in which the balls2 are piled in several layers in the ball supply section 1, even if the balls 2 can be vibrated by the vibrator 3, the balls 2 just rock, but do not skip largely upward because the balls 2 interfere with each other. As a mechanism of this embodiment is designed in a prerequisite condition that the balls 2 largely skip, a ball suction rate to the head 4 is slow in a condition that a skipping distance is short. Besides, if a high ball suction rate is required for the head 4, in spite of a high possibility that the balls 2 are pressurized by the head bottom 5, it is necessary to enter the head bottom 5 into a group of vibrating balls.

On the other hand, in the case of Fig. 2(B) in which the balls 2 lie sparsely in one layer in the ball supply section 1, the balls skip upward by the vibrator 3. In order to largely skip the balls 2 upward by the vibrator 3, it is preferable to control an amount of the balls 2 in the supply section 1 to lie in one layer and besides sparsely on a bottom of the ball supply section 1, that is, the container.

In the case where the balls lie even in one layer, the balls do not skip high upward if the number of balls is too large, because the balls 2 interfere with each other. To the contrary, in the case where the number of balls 2 is small, the balls 2 skip largely upward, but it takes a long time to suck up the balls 2 to all of the suction holes 25 which are provided on the head bottom 5.

In this embodiment, it is preferred that an area where the balls 2 occupy is about 50% by area for a bottom area of the ball supply section 1. In this invention, it is preferred that the area where the balls occupy is 5 to 80% by area for the bottom of the ball supply section 1, and it is more suitable that it is 20 to 70%.

In the case of sucking up skipping balls 2 to the head 4, the head bottom 5 is moved in the range where the balls 2 are skipping so that the head 4 sucks up the balls 2 which come near the suction holes 25 provided on the head bottom 5. When sucking up the balls 2 to the head 4, it is not necessary, in this condition, to counterbalance the head weight, because the balls 2 are not pressurized by the head bottom 5. The head 4 can suck up the balls 2 in a condition moving the head 4 which is clamped in order to prevent from vibration

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Further, a mechanism which spouts air from under the balls 2 piled up also can rock the balls 2 in the same way as the vibrator 3. In the case adopting this mechanism, if the head 4 is not lowered in the group of the balls 2, it takes a long time to suck up the balls 2 and there

happen the suction holes 25 which can not suck up the balls 2, because a height where the balls skip is very low.

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If the head bottom 5 in a clamped condition is lowered into a group of the balls 2, it happens that the balls 2 are forcibly pressurized and stick firmly to the suction holes 25 provided on the head bottom 5. Therefore, when the balls 2 are mounted on the workpiece 12, it happens the balls 2 (remaining ball) which are not mounted on the workpiece 12 remain on the head 4. So, when lowering the head bottom 5 into the group of the balls 2, it is necessary for the head weight to is counterbalanced. In this way, when sucking up the balls 2 to the head 4, whether it is necessary or not to counterbalance the head weight is determined by a condition in which the balls 2 skip.

The workpiece 12 is sent onto the XYZθ table 13 for the workpiece from a magazine by a loader (not shown). The XYZθ table 13 for the workpiece is composed of an X-table for taking an action in the X-direction in a plane, a Y-table for taking an action in the Y-direction in a plane, a Z-table for taking an action upward and downward and a θ-table for a rotation, and the θ-table is on the upper stage. The holding table 23 for fixing the workpiece 12 is attached on the θ-table. In the present invention, the positioning mechanism for the workpiece 12 is composed of the XYZθ table 13 for the workpiece and the holding table 23

Fig. 3 shows the holding table 23. Fig. 3(A) is a plan view and Fig. 3(B) is a cross-sectional view. In the holding table 23 are setup a plurality of holes 23a for inserting suction pads 24 and tubes 23b for connecting with the holes 23a and a vacuum pump 10. The workpiece 12 which is transferred onto the holding table 23 is absorbed by the suction pads which are vacuum-absorbed such that a bow of the workpiece 12 is leveled. A bellows-shaped suction pad 24 deforms in axis direction easier than a plain-shaped suction pad; therefore, the bellow-shaped suction pad 24 is superior to the plain-shaped suction pad in the performance for leveling the bow of the workpiece 12. The bellows-shaped suction pads 24 are setup in the holding table 23 so that each tip of the pads 24 is put 1 mm above the holding table 23.

A preferred length in which each tip of the bellows-shaped suction pads 24 protrudes above the holding table 23 is in the range 0.2mm to 5mm, but it depends on a degree of the bow of the workpiece 12. In the case where an area of the workpiece 12 is larger than or equal to 5 cm×10 cm and its thickness is thinner than or equal to 0.1 cm, ball mounting errors increase

rapidly in the step of mounting the balls. The bellows-shaped suction pads 24 are effective in a large size such as the above-described workpiece.

In order to mount the balls 2 sucked up to the head 4 on predetermined places (for example, electrodes 29 in Fig. 8) of the workpiece 12, it is desirable to align the head 4 and workpiece 12. Alignment of the head 4 and workpiece 12 is performed by recognizing predetermined definite marks, calculating position data of the predetermined marks, and then driving the XYZθ table 7 for the head and the XYZθ table 13 for the workpiece. Position data of marks input by hand and image data captured by a scanner in advance are used as reference data so as to determine whether the image data match the predetermined marks or not. When the head 4 is moved a long distance, a drive unit different from the XYZθ table 7 for the head is used. That is, an X-direction drive unit 22 is employed in the X-direction and a Z-direction drive unit 9 is employed in the Y-direction. Each of these drive units is composed of a servomotor with an absolute encoder and a ball screw assembly. Position data in programs for moving the head 4 are input through a teaching method.

Methods for feeding flux which is necessary for soldering comprise: a printing method in which the flux is printed on the predetermined positions of the workpiece 12; a transferring method in which the flux applied on each tip of pins is transferred on the predetermined positions of the workpiece 12; and a dipping method in which a lower part of the ball 2 which is sucked up to the head 4 is dipped into the flux and then the ball 2 with the flux are mounted onto the workpiece 12. This invention may use all of the above-mentioned flux feeding methods. Also in this embodiment, a flux feeding mechanism 26 is arranged near the ball supply section 1.

FIG.4 is a second embodiment in relation to a peripheral portion of the head 4 for a ball mounting apparatus of the present invention, and a cross-sectional view showing a mechanism in which a total of the head weight and a pressing force by a cylinder 15 counterbalances with an energized force of a spring member 16 and a clamping device for clamping the head 4 to the lower positioning 18 by pressurizing the head 4 downward with the cylinder 15. Further, this head 4 is designed a nearly same structure as the head 4 of the first embodiment showing in Fig. 1, but each of them is slightly different from position of the cylinder 15, structure of the case 14, etc. Numeral 4 denotes a head. Numeral 5 denotes a head bottom. Numeral 14 denotes a case. The cylinder15, the spring member 16, the slider 17, the lower positioning 18 and the upper positioning 19 are attached in the case 15. The head 4 is fixed on one end of the cylinder 15. The

spring member 16 is designed to have an energized force which is able to lift the head 4 upward. The head 4 and spring member 16 is arranged in the case 14.

Fig. 4 shows a state which the total of the head weight and the pressing force of the cylinder 15 counterbalances with the energized force of the spring member 16. Because this counterbalance mechanism keeps counterbalance with the energized force of the spring member 16, the balanced condition is easily restored by the spring member 16 expanding and contracting in the case where the balanced condition is broken.

It is most preferable that the energized force of the spring member 16, in a condition of equalizing a pressure of the cylinder 15 to zero, is designed to be a force by which the head 4 can be lifted to the upper positioning 19. Also, it is preferable that the energized force of the spring member 16, in the condition of equalizing the pressure of the cylinder 15 to zero, is designed to be the force by which the head 4 is hold between the lower positioning 18 and upper positioning 19. Moreover, the energized force of the spring member 16, in the condition of equalizing the pressure of the cylinder 15 to zero, may be designed to be the force by which the head 4 remains on the lower positioning 18. But, in this case, the force by which the head 4 is pressurized to the lower positioning 18 may be reduced under 1Kgf by the energized force making the spring member 16 return upward. If the force by which the head 4 is pressurized to the lower positioning 18 is in excess of 1Kgf in spite of being reduced by the energized force of the spring member 16, the balls 2 stick to the suction holes 25 provided at the head bottom 5. Therefore, the balls 2 are not transferred onto the workpiece 12, so that extra balls occur.

Whenever a model of the workpiece 12 is changed, the head 4 is changed in order that the head 4 can keep up with the model. In the case of changing the head 4 and the spring member 16 together, it takes a long time to change over other model. So as to be designed not to need to change over the spring member 16 every time the head is changed, the energized force of the spring member 16 is designed to be a force by which the spring member16 can lift the head 4 above the upper positioning 19 and counterbalance with the head weight only by adjusting the pressure of the cylinder 15. Consequently, the spring member 16 is able to correspond to every kind of the head 4, so that the spring member 16 can reduce model changing time. Moreover, easily changing over (so-called one touch exchange) the head 4 becomes possible.

FIG.5 is a third embodiment in relation to the head 4 and its drive unit of the ball mounting apparatus of the present invention, and a side view showing a mechanism which

includes a counterbalance mechanism for the head 4, a clamping device for the head4 and a mechanism section including the moving mechanism for the head 4. A mechanism for counterbalancing the head weight is an improvement of the counterbalance mechanism shown in the first and the second embodiment. Numerical 4 denotes a head having cavity 6. Numerical 5 denotes a head bottom being disposed the suction holes 25. Numerical 15 denotes a cylinder. Numerical 16 denotes a spring member. Numerical 17 denotes a slider. Numerical 18 denotes a lower positioning. Numerical 19 denotes an upper positioning. Numerical 20 denotes a motor. Numerical 21 denotes a ball screw assembly. This mechanism is a structure devised to easily assemble and handle the apparatus and to get rid of the case 14 which covers the head 4 and the spring member 16 (refer the second embodiment).

FIG. 5 shows a state in which the total of the weight of head 4 and the pressure of the cylinder 15 counterbalances the energized force of the spring member 16. The spring member 16 provides the same characteristics as described in the first and second embodiments. The moving mechanism for the head 4 is composed of the XYZθ table 7 for the head, the base 8, the X-direction drive unit and the Z-direction drive unit like the first and second embodiments.

Fig. 6 shows one example in relation to a flux feeding mechanism 26 for applying the flux 27 to the balls sucked up to the head 4 and supplying the flux. The flux feeding mechanism 26 has a shallow opening for storing the flux 27. The opening is larger in area than the head bottom 5, and beside a depth of the opening is matched with an amount of the flux 27 which should be applied to the balls 2. The flux 27 is formed into a flux layer with a plane surface by horizontally moving a blade 28.

FIG.7 shows a ball mounting method according to an embodiment of the present invention and a flowchart with relation to a first embodiment of a method carried out by using the ball mounting apparatus shown in Figs. 1 to 6. The first embodiment of the ball mounting method is composed of the steps of applying flux 27 to the lower part of sucked balls 2 and mounting the balls 2 applied with the flux 27 on the workpiece 12, after the step of sucking up the balls 2 to the head 4.

In step 1, the head 4 is pressurized downward by the cylinder 15 and clamped to the lower positioning 18 to prevent from vibration while the head 4 is moved and when the head 4 is stopped. A clamping force is set at 7Kgf. In step 2, the head 4 is lowered near to the container of the ball supply section 1 in which several layers of the balls 2 are piled. The head bottom 5 is not

inserted into a group of the balls and is kept 1cm above a top face of the group of the balls. In step 3, a pressure of the cylinder 15 for clamping the head 4 is reduced, and the head 4 is released from the clamped condition, and the head weight is counterbalanced with the energized force of the spring member 16. Further, the cavity 6 of the head 4 is vacuumed by the vacuum pump 10, and the head 4 is set in the condition to be able to suck up the balls.

In step 4 which is a step of sucking up the balls 2, the balls 2 are sucked up to the head 4 by lowering slowly the head bottom 5 into the group of the balls being floated by the vibrator 3. After sucking up the balls 2 for 3 seconds, the head 4 is raised 1 cm. The balls 2 may be always floated by the vibrator 3, but in order to prevent from deformation and aggregation of the balls 2, it is more desirable to begin vibrating the balls 5 seconds before beginning sucking up the balls 2.

In step 5, the head 4 is pressurized downward by the cylinder 15, and then pushed to the lower positioning 18, and clamped 7Kgf so as to prevent from vibration of the head 4 while the head 4 is moved. In step 6, after the head 4 is raised upward at the speed of 10 cm per second, and then moved in a horizontal direction above to the flux feeding mechanism 26 at the speed of 30 cm per second, the head 4 is moved near the flux layer formed to a predetermined thickness at the speed of 10 cm per second.

In step 7, in the case where the flux layer filled with in the container of the flux feeding mechanism 26 is thicker than a depth where the ball 2 are dipped into the flux 27, the tips of the balls 2 sucked up by the head 4 are dipped into the flux 27 and lower parts of the balls 2 are applied with the flux 27. The flux 27 adhering to the head bottom 5 causes extra balls adhering to the head bottom 5 in the step (step 4) of sucking up the balls 2 to the head 4. In order for the head bottom 5 not to touch the flux 27, Z-direction position control is practiced.

On the other hand, in the case where the flux layer is thinner and equal to the depth where the balls 2 are dipped into the flux 27, after the head weight is counterbalanced substantially to zero, the head 4 is moved to the bottom of the flux layer. In this case, since the head weight is counterbalanced substantially equal to zero, the balls 2 do not stick tightly into the suction holes 25 provided at the head bottom 5, so the extra balls do not occur in the step of mounting the balls 2 onto the workpiece 12.

In step 8, the head 4 is raised upward under a clamped state, then moved above the workpiece 12, and consecutively lowered to 0.5 cm above the workpiece 12. A moving speed is

the same as that of the step 6. In step 9, when moving, in order to prevent from overload added to the balls2, the clamped condition of the head 4 is canceled in the manner the same as that of the step 3. In step 10, the head 4 is lowered slowly until the flux 27 applied on the lower parts of the balls 2 touches to the workpiece 12.

Next, an internal pressure of the cavity 6 in the head 4 is returned back to atmospheric pressure and the balls are mounted on the workpiece 12 with the help of the self-weight of the head 4 and an adhesive strength of the flux 27. Then, the head 4 is raised slowly 1 cm and the ball mounting process is completed. In step 11, the head 4 is clamped again and returned to the step 2. In step 12, the workpiece 12 is sent to a next process of step 11, such as an inspection, a reflow soldering or a cure process.

In the case where the balls 2 which sparsely lie in one layer in the ball supply section 1, the balls 2 are largely floated upward by the vibrator 3. Therefore, it is unnecessary to cancel the clamped condition of the head 4 when sucking up the balls 2, because there is not any possibility that the head 4 pressurizes the balls 2. In this case, step 3 and step 5 may be omitted. Since a floating distance of the balls is short in the case where the balls 2 are floated by gas, once the head weight is counterbalanced, the head bottom 5 is moved into the group of the balls 2 and sucks up the balls 2.

In the case where the balls 2 are smaller than or equal to 300 microns in diameter, the balls 2 are gathered and agglomerated under the head 4 through streams of air which are absorbed through the suction hales 25 provided at the head 4. If the balls 2 are agglomerated, the balls 2 can be scarcely sucked up. In this case, even on the way of sucking up the balls 2, the head 4 is raised upward and stopped sucking up the balls 2, and once agglomeration of the balls 2 is loosed by vibration, the head 4 is lowered and sucks up the balls 2 again. In the case where the balls 2 are smaller in diameter and the mounting balls 2 is numerous, it is necessary to repeat the above process several times.

Further, on the way of sucking up the balls 2, sucking up the balls 2 is temporarily stopped by weakening suction pressure in the range in which the balls 2 do not drop, and after agglomerated balls 2 are dispersed, the balls 2 are sucked up again. In this manner, the same performance can be obtained.

In the step 7 of applying the lower part of the ball 2 with the flux 27, each ball 2 is dipped in the flux 27 to a depth equal to 1/10 to 3/5 of the diameter of each ball 2. It is more preferable

to be dipped in the flux 27 1/5 to 1/2 of the diameter. The amount of the flux 27 coated on the ball 2 depends on a depth in which the ball 2 is dipped into the flux 27. Though the depth dipping the ball 2 into the flux 27 deviates only 5 μm in the case in which the ball 2 is 100μm in diameter, the amount of the flux 27 coated on the ball 2 fluctuates approximately 20%.

A reference position in the Z-direction is determined by using a level gauge, but it sifts as temperature changes in operation. If compensations for the position in the Z-direction are not frequently carried out, positioning errors increase. In the case where the balls 2 which are smaller than or equal to 200 microns in diameter are mounted on a curved workpiece, pickup errors increases, if the compensations are not carried out frequently.

Fig. 8 schematically shows a process of mounting the balls 2 onto the pads 29 provided on the workpiece 12 after the balls 2 are dipped into the layer filled with the flux 27 and the flux 27 is applied to the balls 2. Fig. 8(A) shows a state in which the head 4 is moved above the opening filled with the flux 27 which is formed to the thickness corresponding to the amount which should be applied to the ball 2. Fig. 8(B) shows a state in which the balls 2 sucked up to the head 4 counterbalanced the self-weight are lowered to a bottom of the flux layer. Fig.8(C) shows a state in which the head 4 is raised after the flux 27 is applied to the balls 2. Fig. 8(D) shows a state in which the head 4 is moved above the workpiece 12. Fig. 8(E) shows a state in which the head 4 is lowered more after the head 4 counterbalanced by the self-weight is lowered, contacting the flux 27 with the pads 29. Fig. 8(F) shows a state in which the balls 2 applied with the flux 27 are mounted onto the pads 29 provided on the workpiece 12.

In the case of precisely controlling the amount of the flux 27 applied to the balls 2, a following method is preferable. First, a flux layer is formed by a blade in a thickness which corresponds to an amount to be applied, and then the head 4 is performed in the condition in which the head weight is counterbalanced substantially to zero. Next, once the head 4 is lowered until each tip of the balls reaches the bottom face of the flux layer (the bottom of the opening) which is formed to a predetermined depth, the head 4 is raised slowly. Since the head 4 acts as an object of which a weight is zero because the head weight is substantially counterbalanced, the head 4 does not apply substantially any load to each ball 2, even if the head 4 makes each tip of the balls 2 lower still more after each tip of the balls 2 reaches the lower face of the flux layer and contacts with the bottom of the opening. In other words, each of the balls 2 does not stick firmly into the suction holes 25 disposed on the head bottom 4.

In this method, the amount of the flux 27 applied on each ball 2 sucked up to the head 4 does not depend on a depth where each of the balls 2 is pushed into the flux 27, but a thickness of the flux layer. So, the smaller each of the balls 2 is in diameter, the more effective this method is. Specifically, it is effective that each of the balls 2 is smaller then or equal to 500 microns in diameter; further it is more effective that it is smaller than or equal to 300 microns in diameter. It is preferable that the thickness of the flux layer formed in the flux supply mechanism 26 is 1/10 to 3/5 of the diameter of each of the balls 2. It is more preferable that it is 1/5 to 1/2 of the diameter of each of the balls 2.

A second embodiment which is a ball mounting method of the present invention is a process for mounting the balls 2 sucked up to the head 4 on the workpiece 12 on which the flux 27 has been applied to the predetermined places by a printing apparatus. Fig. 9 shows a flowchart of this second embodiment. In step 21, the head 4 is clamped to the lower positioning 18. In step 22, the head 4 is moved above the ball supply section 1. The ball supply section 1 is supplied the balls 2 which occupy approximately 50 % by area. The step 3 in Fig. 7 according to the first embodiment is omitted. In step 23, the head 4 is lowered in the range where the balls 2 skipped and floated by the vibrator 3 can hit the head bottom 5 and sucks up the balls 2 by vacuum (corresponding to the step 4 of the first embodiment). In step 24, the head 4 is moved 1 cm above the workpiece 12 on which the flux 27 is printed on the predetermined positions. In step 25, the head 4 is released from clamping. In step 26, after the head 4 is lowered slowly so that the balls 2 sucked up to the head 4 are dipped into the flux 27 printed on the workpiece 12, an inner pressure of the cavity 6 removes to ambient pressure and the head 4 slowly is raised and transfers the balls 2 on the workpiece 12 with the help of the self-weight of the ball 2 and adhesion of the flux 27. The head 4 is then raised upward 1cm in distance. Through this process, the balls 2 sucked up by the head 4 are transferred on the workpiece 12 with the help of adhesion of the flux.

While the head 4 is raised or after the head 4 is raised, vibrations are imparted to the clamped head 4 in order that the balls 2 do not remain on the head bottom 5. The vibrations are generated by knocking the head 4 with a hammer. The hammer may knock only one time, but the number of knocking is increased up to five times if the balls 2 tend to remain. A knocking force is weaker in the condition in which the head 4 is not clamped than in the condition in which the head is clamped. This method in which the remaining balls are dropped by knocking the head 4

with the hammer is also effective in the first embodiment according to the ball mounting method of the present invention.

Fig. 10(A) shows a front view of the head 4 attached a single-acting cylinder 30 and Fig. 10(B) shows the positions where the head 4 is knocked by the single-acting cylinder 30. A spring is provided inside the single-acting cylinder 30. The single-acting cylinder 30 which is pushed out by air 31 is retrieved to a home position by the energized force of the spring if air pressure is reduced to zero. Numeral 4 denotes a head, numeral 30 denotes a single-acting cylinder, numeral 31 denotes air for driving the cylinder, and numeral 32 denotes positions where the single-acting cylinder knocks an upper face of the head 4. Knocking edge portions of the head is preferable to knocking a central portion of the head 4. In the present invention, the hammer may be the single-acting cylinder 30, an electromagnetic hammer, and so on. The electromagnetic hammer is a conventional one which is composed of a coil, a spring member, a hammer, a magnetic circuit and electrical circuits. As for other vibration method, except the hammer, to prevent the head 4 from the remaining balls, there is a method imparting vibrations with an ultrasonic vibrator. But, the method using the ultrasonic vibrator is inferior to one using the hammer, because vibration energy imparted one time by the ultrasonic vibrator is smaller than by the hammer.

Referring back to Fig. 9, in step 27, the head 4 is clamped to the lower positioning 18. After the step 7, the head 4 returns to the step 22. In step 28, the workpiece 12 on which the balls 2 have been mounted is transferred to a next process.

In the above-described two embodiments, when the head 4 does not suck up any balls, since there is no risk of the balls 2 drop from the head 4 while the head is moved. A travel speed of the head 4 can be faster in the case sucking up no ball than in the case sucking up the balls 2. In order to prevent the head 4 from vibration in a condition in which the head 4 is moved at the speed of 5 to 200 cm per second, it is preferred that the head 4 is clamped to the lower positioning 18 above 2Kgf by the cylinder 15. In the case of moving the head 4 at the speed of 5 cm per second, it is possible to prevent the head 4 from vibration by pressurizing the head 4 to the lower positioning 18 at 4Kgf. In the case where the head 4 slowly stops, the head 4 can be also prevented from vibration by pressuring the head 4 to the lower positioning 18 at 2Kgf.

From the point of view of preventing from vibration, an upper limit of pressure does not exist; but, considering an ability of the cylinder 15 and stiffness of the apparatus, the upper limit of pressure is preferably about 200Kgf. It is more preferably that it is smaller than or equal to

30Kgf. Though the embodiments show the mechanisms which pressurize the head 4 to the lower positioning 18, positions and devices for pressurizing the head 4 are not limited only to these, because a purpose of the present invention is to provide methods for clumping the head 4 so as not to cause vibration. Except the method for pressurizing the head 4 to the lower positioning 18, a method pressurizing an attachment of the head 4 to the lower positioning 18 are also preferable. Moreover, the head 4 may, mechanically or electromagnetically, be clumped in the lateral direction by conventional methods.

In case of stopping the head 4 impulsively, vibration occurs even if the clamping force is strong, hence stopping the head 4 impulsively is not preferable. That is to say, it is preferable that the head 4 is stopped as reducing speed. Acceleration and deceleration are programmed in the range of not causing vibration.

In each embodiment of the present invention, since the head weight largely changes in accordance with production types, the spring member 16 which counterbalances with the head weight is designed to be rather big and to have spring constant and length which can energize the head 4 to the upper positioning 19 when the pressure of the cylinder 15 is zero by atmospheric pressure. In this manner, the spring member 16 may be designed to commonly be able to be used.

In each embodiment of the present invention, it is preferable that the balls 2 are conductive balls made of solid metals or insulative balls coated surfaces with conductive materials. The conductive balls made of the solid metals may be solder, gold, silver, copper, nickel balls and so on. The conductive balls made of the insulative balls coated with conductive materials may be plastic, glass, quartz or alumina balls coated with solder, gold, silver, copper, palladium, tin, or nickel. Compositions of the solder are an eutectic composition, high melting point solder compositions, low melting point solder compositions, lead free solder compositions, etc. The metals may be both mono metal and alloy.

In each embodiment of the present invention, it is suitable, in the case where the ball 2 is made of the solder, that the flux 27 may be composed of base composition which consists of rosin added amine for an activator. In the case where the ball 2 is made of gold, silver, copper, nickel, etc., it is suitable that the flux 27 may be composed of conductive adhesives such as solder cream, silver paste, gold paste and so on, because these metals do not melt to act as solder.

In the present invention, the conductive adhesives include silver paste, gold paste, nickel paste, etc. and beside solder cream.

In each embodiment of the present invention, both an air cylinder and an oil cylinder are suitable for the cylinder 15, but the air cylinder is preferable to the oil cylinder.

In each embodiment of the present invention, the head 4 clamped to the lower positioning 18 by the cylinder 15 separates and moves upward from the lower positioning 18 as the energized force of the spring member 16 comes to exceed through weakening the pressure of the cylinder 15. Just before the head 4 raises from the lower positioning 18, the head weight is counterbalanced apparently to zero. If the pressure of the cylinder 15 is still more weakened, the head raises upward keeping the condition in which the head weight is apparently zero. The spring member's energized force in the upward direction decreases in accordance with the head 4 raising.

A stop position of the head 4 is a point where a total of the head weight and the pressure of the cylinder 15 balances with the energized force of the spring member 16. Since the energized force of the spring member 16 is represented by a function of the length of the spring member 16, the spring member 16 shortens slightly to balance as the pressure of the cylinder 15 decreases slightly. On the contrary, in the case where the pressure of the cylinder 15 increases slightly, the spring member 16 elongates slightly in order to balance. Therefore, the head position (Z direction) in the condition in which the self-weight of the head 4 is counterbalanced is represented by a function of the self-weight of the head 4, the energized force of the spring member 16 and the pressure of the cylinder 15. In the case where a relation of these three elements changes or same disturbance is added to, the head position (Z direction) moves, but less in comparison with conventional cases.

In each embodiment of the present invention, the head weight need not be counterbalanced to zero like the foregoing description. That is to say, if a deviation of the counterbalance for the head weight is less than 1Kgf, practical problems rarely happen. It is more preferable that it is less than 100gf. In this case, the head 4 is held on the lower positioning 18 and the head 4 can be accurately positioned, even in the condition in which the head weight is counterbalanced substantially to zero (the range in which the balls does not stick tightly to the suction holes 25). In the case where the deviation of the counterbalance is less than 100gf, a force acting on one ball 2, in the head 4 which has 5,000 suction holes, averages 0.02gf, so there

is no chance for the balls to stick firmly to the suction holes 25. This load is less than an impulsive load which is applied with when the balls 2 is sucked up to the suction holes 25 by vacuum.

Beside, the energized force generating device which lifts the head 4 upward may be other spring such as a plate spring instead of the spring member 16 which is a coiled spring, rubber, or elastic materials made of synthetic resins and others instead of the spring. Further, it is suitable, instead of tugging and lifting the head 4 by the spring member 16, that the spring which is attached under the head 4 may be designed to push and lift the head 4 upward

The present invention is suitable to fix circuit components, such as IC and so on, to a substrate, and further available to use as an apparatus which mounts resin balls to predetermined positions and a section of an apparatus which assembles balls for a ball bearing to a bearing. Moreover, the ball 2 is described as sphere, but shapes of the ball 2 may be elliptic, cylindrical, and so on.

The present invention has the following advantageous effects. It is possible to avoid the balls which were stuck to the head and vibration which is occurred to the head by providing both a spring member energizing the head upward and a clamping device, for example, one composed of a cylinder and a lower positioning. Consequently, the present invention can greatly contribute toward industrial developments of the ball mounting apparatus which is built in a counterbalance mechanism. Further, counterbalancing the head weight can be simply carried out by adjusting the clamping device, for example, adjusting pressure of the cylinder, with the help of a spring providing an energized force which is able to lift the head above the lower positioning. The clamping device which is composed of the cylinder and the lower positioning is able to accurately position the head (in the Z direction). It is possible to use a curved workpiece, because the curved workpiece is straightened flatter by fixing the workpiece to a holding table by using bellows-shaped suction pads.

Furthermore, a ball mounting method in which the balls do not stick and the head does not vibrate is able to be put into practical use by a method for clamping the head when the head is moved and releasing a clamping force when the balls are mounted on the workpiece. Even in the case where the head moves at the speed of 5 to 200 cm per second, the head can be prevented from vibration by clamping the head with a load of 2 to 30Kgf. The suction efficiency of the head is improved, because the balls can be largely skipped upward by vibrating the balls in a

sparsely scattered condition. The disadvantage that the balls aggregate can be overcome by intermittently sucking up the balls, and beside it is possible to efficiently suck up the balls to the head.

The predetermined amount of the flux can be precisely applied to each of the balls without sticking the balls to the suction holes by dipping the balls sucked up by the head of which the weight is counterbalanced into the bottom of the flux formed to the predetermined thickness. It is possible to mount the conductive balls precisely coated with the predetermined amount of the conductive adhesive on the workpiece with the help of the step of applying the conductive adhesive to the conductive balls.

It has been found out that problems do not occur even if the counterbalance of the head weight deviates less than or equal to 1Kgf. Consequently, the present invention has been able to greatly contribute toward wide developments of a counterbalance type ball mounting method which counterbalances the head weight by adopting the clamping force.

The balls remaining on the head can be dropped without big vibrations of the head, with the help of knocking the head with a hammer after the steps of mounting the balls to the workpiece and then clamping the head.

It has been successfully demonstrated that the present invention prevents the balls from sticking to the suction hales when sucking up the balls or prevents from overload when mounting the balls on the workpiece, because the head weight is counterbalanced substantially to zero by appropriately adjusting with the energized force of the spring member which is provided in order to generate the energized force and the pressure of the cylinder which is provided in order to clamp the head.

It will be apparent to those skilled in the art that various modifications and variations can be made in the ball mounting method and apparatus of the present invention without departing from the spirit or scope of the inventions. Thus, it is intended that the present invention cover modifications and variations of this invention that come within the scope of the appended claims and their equivalents.